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Petrophysical Analysis of Palaeozoic Carbonate Rocks in Lafarge Quarry, Perak, Malaysia

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Key words: Dolomitization, porosity and permeability, lithology, mineralogical analysis, XRF

Abstract: Dolomitization is a complex issue because it can develop and destroy matrix porosity. In many cases, dolomitized rock has better reservoir properties than limestone. This is because chemically during the dolomitization process, two moles of calcite are transformed to one mole of dolomite, causing a net rise in porosity. However, there are few factors that need to be considered as they may affect the porosity during dolomitization such as the characteristics of precursor sediments, subsequent leaching and cementation. The main objective of the study is to analyze the porosity and permeability of carbonate rocks in Kinta valley, Perak in relation to lithology of rocks. Systematic outcrop sampling technique is applied in collecting the samples for laboratory analysis. Core plugs were prepared for further analysis. Porosity and permeability of 13 selected core plugs from Hill E and B of Lafarge quarry were measured by using poroperm and helium porosimeter equipment. Hand samples were crushed by using grinder machine into powder form for X-Ray Fluorescence (XRF) analysis. Mineralogical analysis is used to determine either the rocks are calcitic or dolomitic and to match with lithology. In average, the results show limestone has the highest porosity and permeability with the highest calcium content. While, argillaceous limestone has the lowest porosity and permeability compared to others. Dolomite rocks has slightly lower porosity and permeability than limestone but higher than argillaceous limestone.

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INTRODUCTION

The study is conducted in Lafarge quarry, located in the northern part of Kinta valley, Perak. Geologically, Kinta valley lies beneath the Kinta limestone and it has been dated from Devonian to Permian age[1]. The study sites are mainly composed of limestone and subsequent dolomite with some brecciation. The dolomite in Kinta valley existed due to hydrothermal dolomitization process. The presence of lode tin deposits in Kinta valley indicates hydrothermal in origin which has been discovered in granitoids and sedimentary rocks, mostly in limestone and schist[2]. The granite is pushed up and created a deep-seated fault. The fluids that rich in hydrothermal minerals with some consist of magnesium ion are carried through the deep-seated fault to the surface and altered the rock wall of limestone to dolomite. The limestone has massive and thin bedded varieties, grayish white color with black carbonaceous spots and associated with carbonaceous phyllite. While, the dolomite is massive, pinkish white color and has cut cross the central part of the quarry in N-S direction[3].

Dolomitization is one of the important processes that affect the petrophysical characteristics of the rocks. Based on previous study of dolomite, the porosity is decreasing as dolomite increase up to approximately 50%. Then, as dolomite continuously increase above 50%, the porosity also increases. Later, when dolomite reach up to 80% and above, the porosity and permeability decline uniformly. As it reached 95%, the rock solely become impermeable and porosity is occluded. In overall, it is proven that porosity increases as percentage of dolomite increases[4]. It is common at early stage of dolomitization, dolomite growth is associated with porosity reduction. As dolomite increases, the dolomite crystal develops a space supporting texture that prevent the original porosity from compaction and porosity loss. Then, porosity will reduce again after all carbonate sediment is replaced by dolomite due to higher volume of dolomitizing fluids that pass through the rocks, in which it causes to increase in crystal size and interlocking of dolomite crystal[5]. The dolomite porosity is well preserved if growth of dolomite crystals stopped after the replacement of precursor limestone by dolomite. Dolomite rock has greater physical and chemical strength compared to limestone. Thus, it is more susceptible to porosity preservation[5].

Tectonic settings of Kinta valley: Peninsular Malaysia was divided into three geological belts which are Western, Eastern and Central belts. The origin of Western belt is from a continental block, Sibumasu block that drifted away from Gondwana in Early Palaeozoic time. While, the Eastern and Central belts are part of the single tectonic block, Indochina block[6]. These two blocks met each other during Permian and the subduction of Western belt beneath the Central belt formed a Bentong-Raub Suture zone. These occurrences resulted in the emplacement of granite intrusion underneath and east of Kinta Limestone from Triassic to Jurassic period[7]. The stratigraphy of Western belt is different from eastern and central belts because they have different tectonic origins. Based on Harbury *et al*.[8], the Western belt was tectonically stable

Fig. 1: Geological provinces of Western Malaysia, divided into Western, Central and Eastern belts[9]

in the upper Palaeozoic period. Most of the carbonates in Peninsular Malaysia are widely distributed in Western belt (Fig. 1).

Kinta valley is located at the Western belt of Peninsular Malaysia. Kinta Limestone in the south Perak has been dated in Silurian to Permian age as in Fig. 2. The geological ages of Kinta Limestone varied based on outcrop locations and still questionable[10]. Richardson[11] stated the Kinta Limestone has complex structure, lack of fossils and huge impact of metamorphism.

A thermo-tectonic event is believed to take place in Kinta Limestone during granite intrusion from late Triassic to Early Jurassic[11-14]. This thermal event resulted in recrystallization and dolomitization at certain part of Kinta limestone[1, 15]. Kinta limestone mostly consisted of pure limestone and few dolomites, marbleized limestone and interbedded with schist and carbonaceous phyllites[9].

Folding and faulting of Kinta Limestone take places during Late Permian to Middle Triassic. Later, the limestone was subjected to contact metamorphism by the emplacement of Main Range granite during Middle to Late Triassic to Early Jurassic[16, 17]. Then, felsic fluids (hydrothermal fluids) released from the cooling of granitic magma passed through the lineaments such as pre-existing fractures and faults in Main range granite and along pluton margins in Late Cretaceous thermal events. These lineaments were abundance at the contact between granite and limestone. The intense hydrothermal circulation occurred at the end of Mesozoic[9].

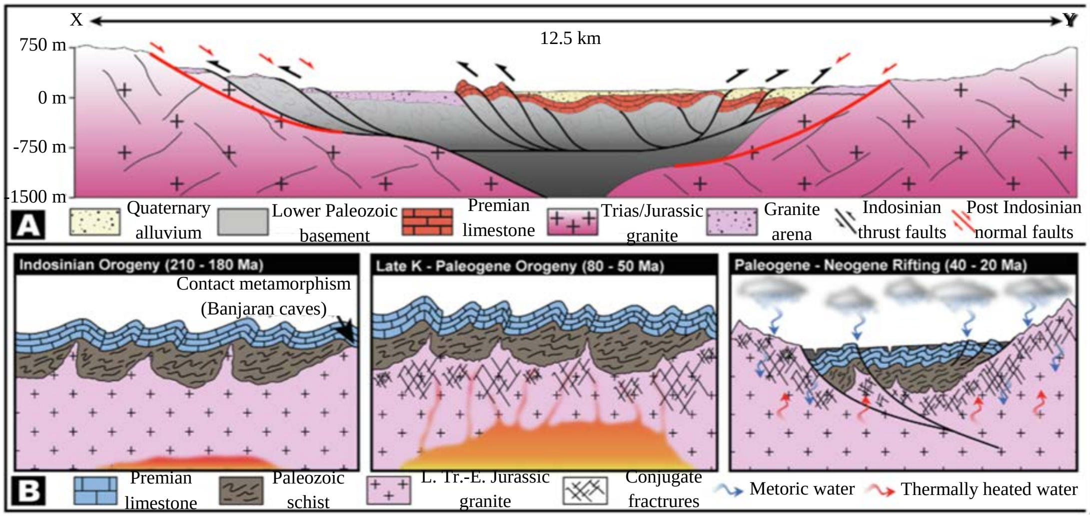

Fig. 2: A cross section of major tectono-magmatic events in and around Kinta valley in the Western belt, Western Malaysia[9]

Geological settings of Kinta valley: Kinta valley is located at the central part of the Perak state. The shape of Kinta Valley is elongated at North to South direction and has length of 50 km with width of 8-21 km and has an inverted V-shaped, in which the valley is broadens as going down to the southern part[18]. The Valley is constrained by two granitic hills; to the west by the Kledang Range and to the east by the Main Range. Limestone hills are coming out from the bedrock in the valley. The limestone which is believed to be the basement of valley is currently covered by alluvium[19]. The localities of the study area are shown as in Fig. 3a. The geological map composed of few lithologies from different geological age. Kinta Limestone is dated from Permian to Silurian as in Fig. 3b. There is time gap upon the range of Kinta Limestone age because of missing fossil assemblage from upper Devonian to lower carboniferous.

Rajah[19] has grouped Kinta formation into six types of rocks which are calcareous rock, argillaceous rock, arenaceous rock, tourmaline-corundum rock, granitoids and alluvium. Then, Meng *et al*.[12] updated the geology of Kinta valley into 5 main lithologies of Kinta valley which are interbedded sandstone and mudstone, shale, limestone, granite and alluvium. The oldest formation is interbedded sandstone and mudstone that formed probably during Devonian age[2]. Then, shale was deposited during Carboniferous to lower Permian age and mostly found in the southern part of the Kinta valley[2]. The Kinta valley schist underlie beneath the limestone and interbedded with the former at few localities. The limestone and schist were possibly folded and metamorphosed at the end of the Permian age (Suntharalingam, 1968). After the folding and metamorphism of limestone and schists, a tectonic event occurred, in which hot molten granite (Main Range and Kledang Range) intruded into the country rock during the very Late Triassic[1, 2]. The texture and composition of the limestone also changed through contact metamorphism caused by granite intrusion. The northern part of Kinta valley is less metamorphosed compared to southern part[20]. In Kinta limestone, the limestone mostly striking north-south direction trend. However, the bedrock is gently folded and form anticline structure due to local deformation[3]. Ingham and Bradford[20] stated the depositional environment of Kinta valley was shallow marine that consists of carbonaceous terrigenous sediment in which mostly clear has warm climate and intercalation between argillaceous lenses with the limestone.

Pierson *et al*.[21] has mentioned that the limestone sequence of the Kinta Valley has depositional environment of a deep marine lower slope based on the interpretations of sedimentary structures and rock components in the limestone. The existence of the slumps in the Kinta valley show the direction of slumping to the west, indicating that shallow-water carbonate sediments of the margin and lagoon facies that may located to East of the Kinta valley.

These difference in explanations have been validated with relation to the age of Kinta limestone. After the Sibumasu terrain collides with Indochina terrain, deep basinal deposits during late Devonian to early carboniferous with slow rate of deposition and has slumps structure. Then, subsequent shallower carbonate deposits from late carboniferous to Permian[22].

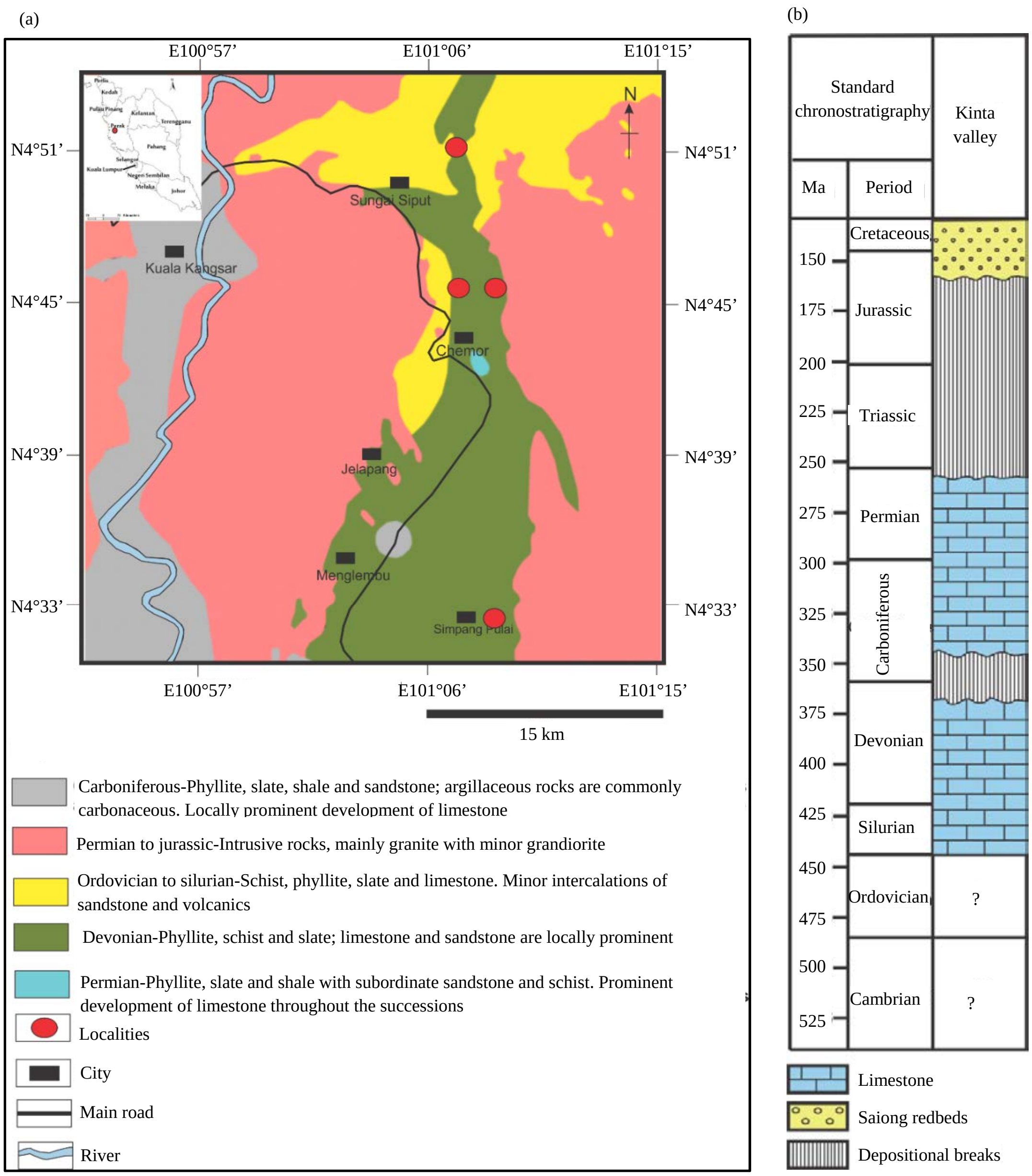

Fig. 3(a, b): (a) Geological map of Kinta Valley show the localities of collected samples and main lithologies (modified from Mineral and Geosciences Department of Malaysia) and (b) Stratigraphic column of Kinta valley, Perak. Kinta Limestone is dated from Silurian to Permian with time gap from upper Devonian to lower carboniferous[6]

MATERIALS AND METHODS

Geological fieldwork was conducted to collect the samples, construct sedimentary logging and do some observations. Sedimentary logging was constructed based on outcrop descriptions such as the grain size, sorting, angularity, colour, lithology, structure and additional features. During the field, hydrochloric acid with 10% of 37 mol concentration is used to distinguish between limestone and dolomite rocks.

The block samples were collected horizontally based on systematic sampling technique and the accessibility of the outcrop. The 40 block samples were successfully being cored and trimmed to 1inch diameter and 2 inches length. The rest of the samples are defect cores due to highly fractured block samples. Detailed core plug descriptions helped to support the geological outcrop observations. The visual porosity was estimated before from the core plug by considering the visible micropores and how quick it absorbs water. Then, 13 samples were

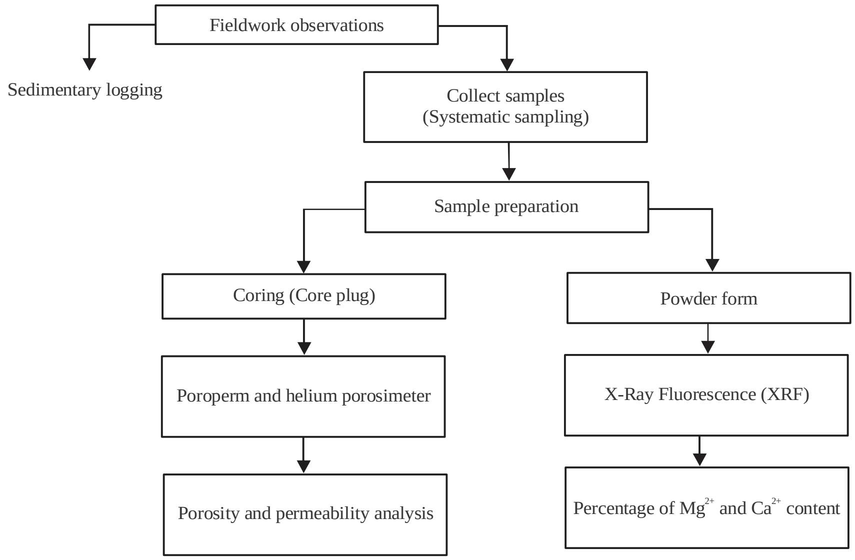

Fig. 4: Flowchart shows involving works in this study

selected from Lafarge quarry in Hill E and B for further analysis such as poroperm, helium porosimeter and X-Ray Fluorescence (XRF). The interpretations were made based on the results obtained. The link of porosity and permeability were analysed with magnesium and calcium ion as the main constituent minerals in limestone and dolomite rocks (Fig. 4).

RESULTS AND DISCUSSION

Outcrop observation and sedimentary logging: By referring to Fig. 5, the outcrop is located at Hill E, Lafarge quarry with coordinate of 4°46'38''N and 101°7'23''E. The outcrop mainly composed of limestone, argillaceous limestone and dolomitic limestone. The bed was tilted almost vertical and striking N-S direction. The outcrop is highly weathered and intensely fractured. Few structures were observed like fractures and breccia. The limestone breccia was found within dolomite bodies in Lafarge quarry, Hill E. It is an indicator of fault-related hydrothermal dolomitization. As has been mentioned by Gregg and Sibley[22], the presence of boxwork or brecciated textures within the crystalline dolomite and sutured crystal contacts suggest that dolomitization process is a post-depositional process and greatly controlled by structurally-induced conduit. This brecciation is commonly found in hydrothermal region. Furthermore, calcite crystal growth was also found within the outcrop and it shows the presence of karst or paleo-cave. Besides, the stylolite is found within the core plug samples. Stylolites result from pressure solution. It reduces the porosity and acts as permeability barriers.

The color changed from darker grey to white towards the younger bed. This could give us some hints on the sea level cycles during that time. Most of the darker colour indicates the rock has high content of mafic minerals like magnesite and iron in which it indicates the drowning phase of carbonate rock. While, the lighter color indicates rock has low content of mafic minerals and give a clue the carbonate rock was exposed to the surface during that time. Phase of exposure occurs when carbonate rock is exposed to the shallow surface because of sea level drop, while phase of drowning occurs when carbonate rock is submerged to deep area due to high sea level. The grain size also changed from medium grain to very fine grain towards younger bed as in Fig. 6. The texture cannot be identified directly from the outcrop because the limestone texture has changed due to contact metamorphism and hydrothermal dolomitization. However, it can be determined in the further study under thin section by looking at the crystal growth. The sorting also changed from moderate- poorly sorted to well- sorted grain.

Another outcrop at Lafarge quarry is Hill B as in the Fig. 7. The main lithology is crystalline limestone, argillaceous limestone and dolomite. The color varied depends on the lithology. Dolomite has pinkish in color, while crystalline limestone is white to light grey and argillaceous limestone has dark grey color. The bed is tilted and few structures observed like en-echelon faults, reversed fault, right strike slip fault. The outcrop is highly fractured and weathered. There is karstified zone near to dolomite zone. It has thin black lamination (bio-lamination), calcite vein infill and stylolite. The grain size is mostly fine to very fine grain and moderate to well-sorted. Pyrite is also found in the outcrop. Both of Hill E and B in Lafarge quarry show almost same distribution types of lithology and geological features.

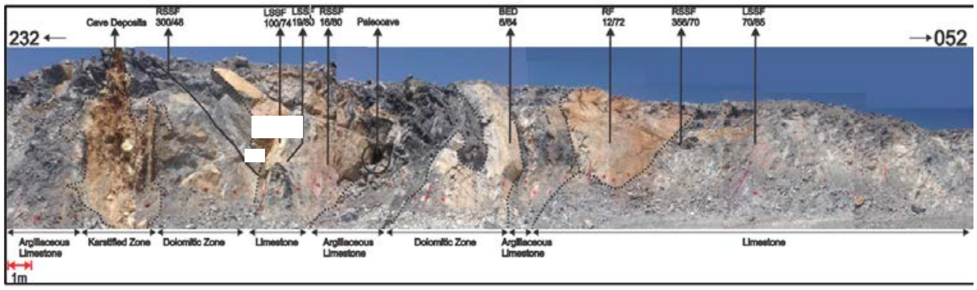

Fig. 5: Representative outcrop of Lafarge quarry (Hill E)

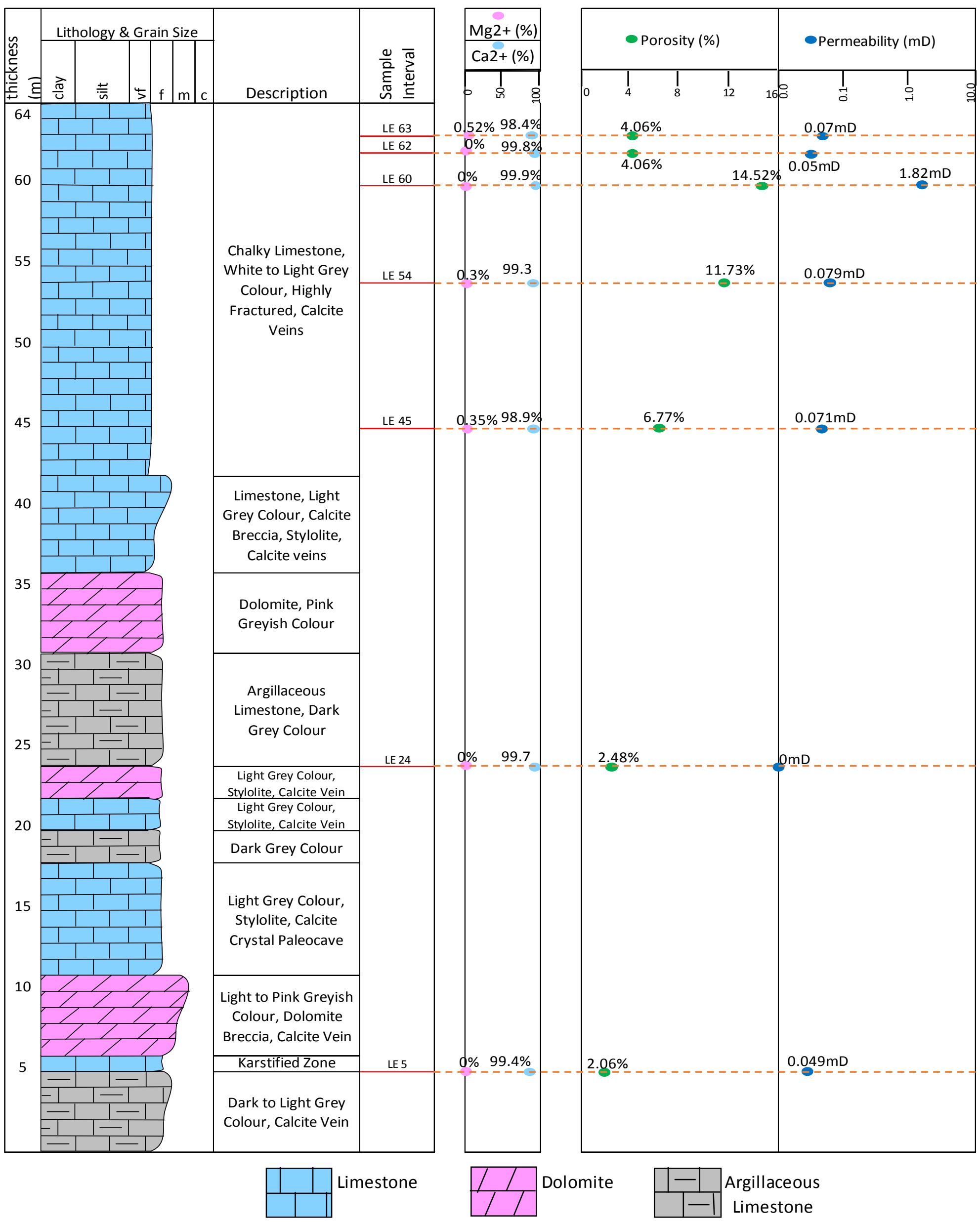

Fig. 6: Sedimentary logging of Hill E; percentage of Ca^{2+} and Mg^{2+} content; porosity and permeability trend along the outcrop with different types of lithology

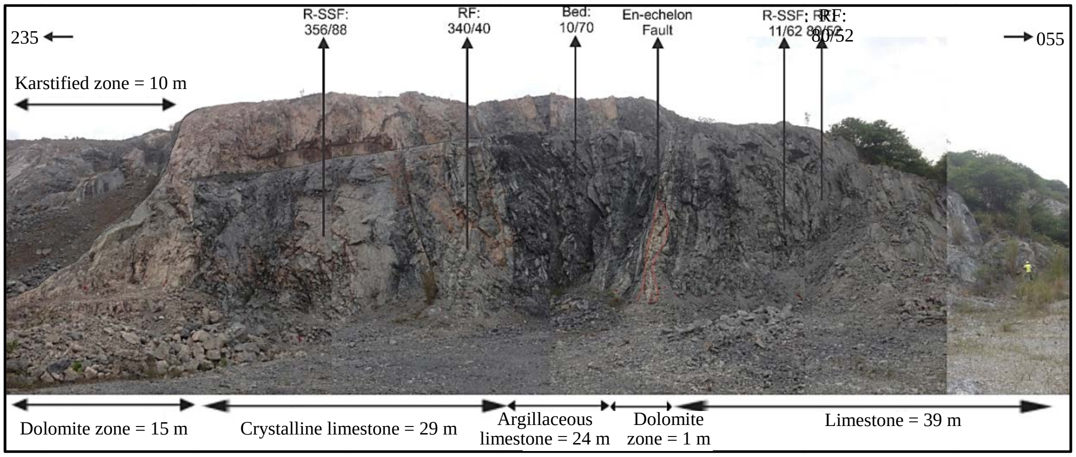

Fig. 7: Representative outcrop of Lafarge quarry (Hill B)

Mineralogical analysis: For mineralogical analysis, the carbonates in Kinta valley were analysed to determine whether they are dolomitic or calcitic. It depends on the percentage of magnesium and calcium. The pure limestone is identified as calcitic where it has highest content of Ca^{2+} as it is the main constituent element of the rock. Physically, the pure limestone has chalky and powdery texture. It has 99.9% of calcium content and 0% of magnesium content. While, argillaceous limestone has 99.4% of calcium and 0% of magnesium content and it is identified as calcitic. The crystalline limestone in Hill B has a small amount of magnesium content which is 0.85 and 97.3% of calcium and it is identified as calcitic with small amount of dolomite minerals. The dolomite has the highest magnesium content and lowest calcium content among other lithology. The magnesium content of dolomite is 13.5% and calcite content is 81.5% and it is identified as dolomitic rocks. The calcium content in carbonate is always high. As the magnesium content increases, the calcium content decreases proportionally.

The pure limestone rock that has 100% of calcite shows the highest porosity and permeability. For dolomite rocks, the porosity is reduced from pure limestone. While, partly crystalline limestone reduced the porosity and permeability value because it has been subjected to metamorphism. Meanwhile, argillaceous limestone has high calcium content and lack of magnesium content. It also reduced the porosity and permeability because of clay content.

The porosity trend of hill E show abrupt changes at limestone sample LE 60 with the highest value of 14. 52% as in Fig. 6. While, in Fig. 8, the trend of porosity in hill B suddenly changed at dolomite sample LB 81 with porosity value of 3.08%.

Porosity and permeability analysis: From the result obtained, most of the carbonate rocks in Lafarge quarry indicate poor potential reservoir, since, they have low porosity and permeability as in Fig. 6 and 8. However, there are few samples tested show good porosity and permeability. For example, the porosity trend of hill E show abrupt changes at limestone sample of LE60 with the highest value of 14. 52%.

For Hill B, the porosity and permeability of the carbonate rocks are very low. The values range from 1.25-3.08% while the permeability range from 0-0.068 mD. The lowest porosity and permeability belong to argillaceous limestone. The porosity is reduced when there is the presence of clay. The moderate porosity and permeability referred to crystalline limestone. The porosity value is 1.47% and permeability value is 0.042 mD. The highest value of porosity and permeability in Hill B belong to dolomite rocks with 3.08% and 0.063 mD.

For Hill E, the lowest porosity and permeability belong to argillaceous limestone. The permeability occluded and the porosity is very low (2.06%). The porosity values of limestone range from 2.48-14.52% and permeability value from 0-1.82 mD. Limestone sample LE 60 has the highest porosity and permeability. The porosity value of the limestone is 14.52% and permeability is 1.82 mD. It indicates a good reservoir quality. There are visible isolated pores preserve without any in fills.

The porosity of dolomite in Hill B is lower than limestone in Hill E probably because of the growth of late dolomite cement after the replacement of precursor limestone rocks. Locally the rate of precipitation is higher than rate of dissolution. The brecciation also acts as impermeable strata that reduced the porosity.

In many cases, the porosity and permeability values will increase significantly. From the porosity and permeability graph (Fig. 9), most of the rocks have very low permeability and varied results of porosity. The

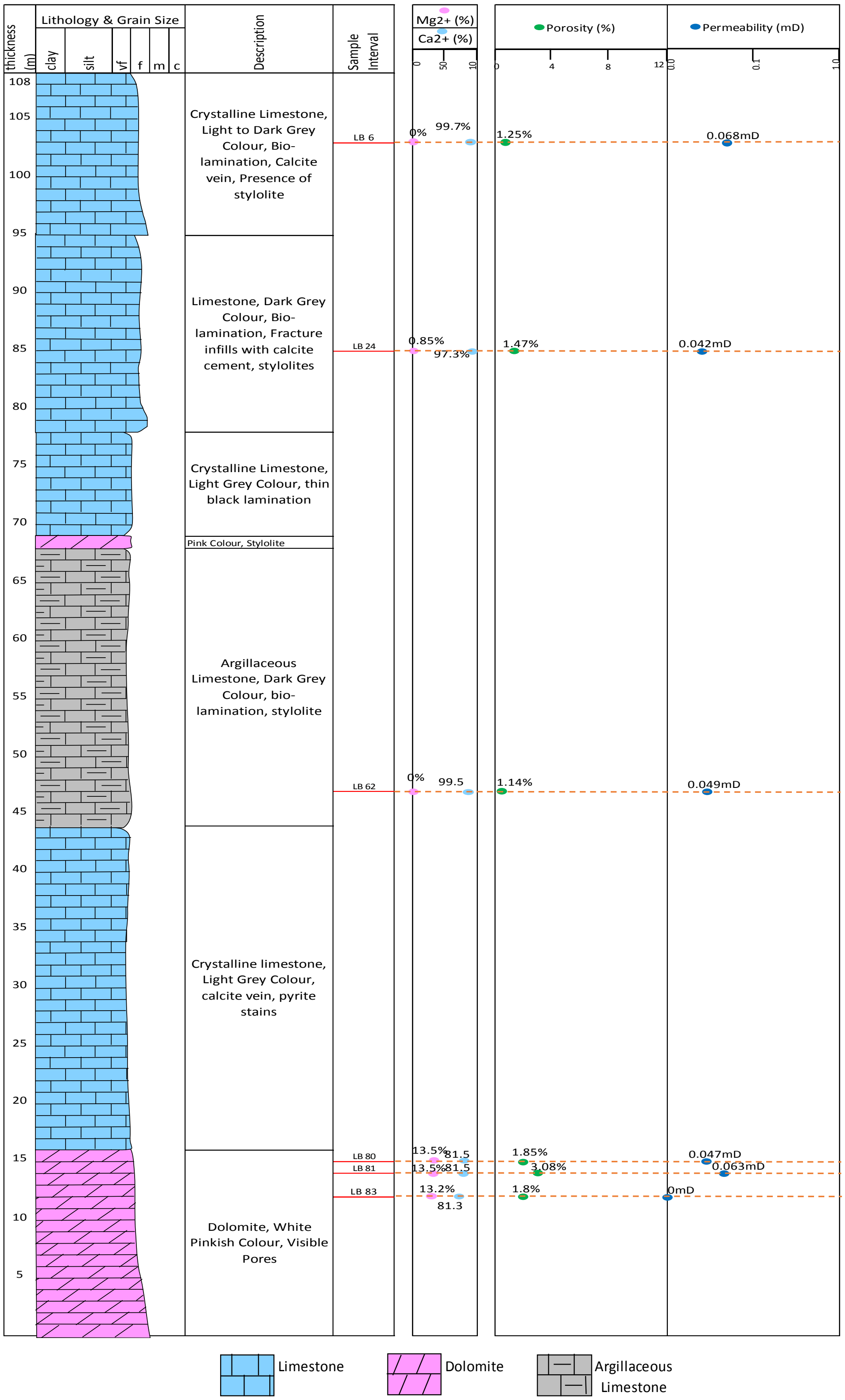

Fig. 8: Sedimentary logging of Hill B; percentage of Ca^{2+} and Mg^{2+} content; porosity and permeability trend along the outcrop with different types of lithology

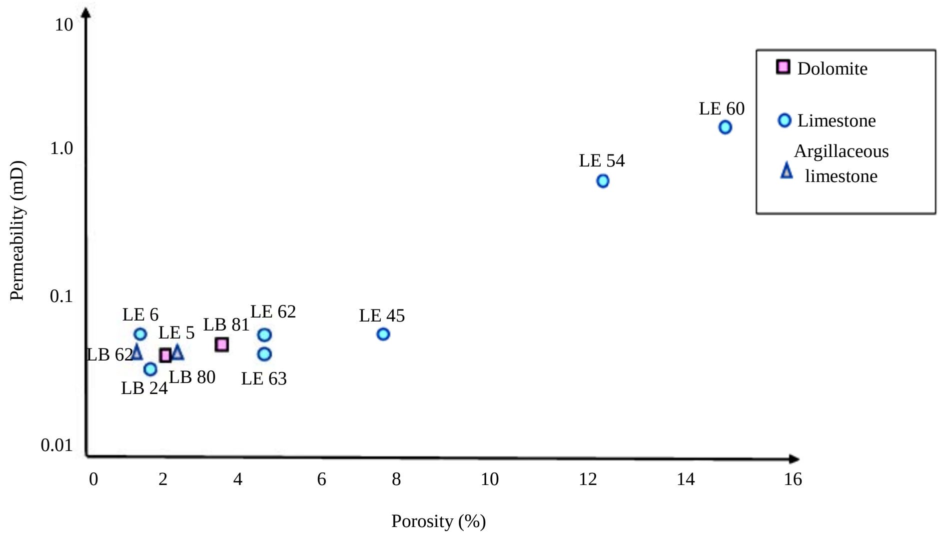

Fig. 9: Porosity versus permeability graph of selected carbonate rock samples in Lafarge quarry. Three different lithology show various range of porosity and permeability

limestone has wide range of porosity value because few of the limestone rocks are partly metamorphosed and crystallized. The porosity reduces as degree of metamorphism increases. The crystalline limestone has lower porosity than chalky limestone. The trend of porosity and permeability not necessarily influenced by magnesium and calcium content only. Other mineral like the presence of clay mineral also contribute to the changes of porosity.

Thus, the lowest average porosity and permeability belong to argillaceous limestone with range from 1.14-2.06% and 0-0.049 mD. The second lowest porosity and permeability value referred to crystalline limestone in hill B with range 2.48-14.52% and 0.042 mD. While, dolomite in Hill B shows the third lowest porosity with range from 3.08-6.77% and the permeability range from 0.063-0.07 mD. The chalky limestone in Hill E shows the highest porosity and permeability value of 14.52% and 1.82 mD.

CONCLUSION

The precursor rocks which is pure limestone has the highest porosity and permeability with highest percentage of calcium and absence of magnesium. While, the dolomite has the second highest porosity and permeability with the presence of magnesium content and lower calcium content compared to other rocks. The dolomitization may reduce permeability significantly but it develops the isolated pores. This observation is made based on core plug samples. The crystalline limestone has lower porosity and permeability compared to chalky limestone and dolomite. The precursor limestone has higher porosity. It reduces when limestone has been metamorphosed and crystallized. The argillaceous limestone has the lowest porosity and permeability. The argillaceous has clay mineral that reduced the porosity and permeability. The trend of porosity and permeability is not necessary depends on the magnesium and calcium content only. The percentage of magnesium and calcium content proved the rocks are calcitic or dolomitic. As conclusion, the porosity and permeability varied based on lithology of the rocks, whereas, the dolomite, crystalline limestone and argillaceous limestone has low porosity and permeability compared to pure limestone.

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REFERENCES

01. Suntharalingam, T., 1968. Upper palaeozoic stratigraphy of the area west of Kampar, Perak. Bull. Geol. Soc. Malaysia, 1: 1-15.
02. Zabidi, H., M. Termizi, S. Aliman, K.S. Ariffin and N.L. Khalil, 2016. Geological structure and geomorphological aspects in Karstified susceptibility mapping of limestone formations. Procedia Chem., 19: 659-665.

03. Mazzullo, S.J., 2004. Overview of porosity evolution in carbonate reservoirs. Kansas Geol. Soc. Bull., 79: 1-19.
04. Sun, S.Q., 1995. Dolomite reservoirs: porosity evolution and reservoir characteristics. AAPG Bull., 79: 186-204.
05. Kassa, S., 2012. Development of Subaerial Karst in Kinta Valley, Peninsular Malaysia. Master Thesis, Universiti Teknologi PETRONAS, Seri Iskandar, Malaysia.
06. Metcalfe, I., 2013. Tectonic evolution of the Malay Peninsula. J. Asian Earth Sci., 76: 195-213.
07. Gebretsadik, H.T., C.W. Sum, G.A. Yuriy, A.W. Hunter, J. Ab Talib and S. Kassa, 2017. Higher-resolution biostratigraphy for the Kinta Limestone and an implication for continuous sedimentation in the Paleo-Tethys, Western Belt of Peninsular Malaysia. Turk. J. Earth Sci., 26: 377-394.
08. Harbury, N.A., M.E. Jones, M.G. Audley-Charles, I. Metcalfe and K.R. Mohamed, 1990. Structural evolution of Mesozoic peninsular Malaysia. J. Geol. Soc., 147: 11-26.
09. Ramkumar, M., N.A. Siddiqui, M. Mathew, B. Sautter and P.X. Hui *et al*., 2019. Structural controls on polyphase hydrothermal dolomitization in the Kinta Valley, Malaysia: Paragenesis and regional tectono-magmatism. J. Asian Earth Sci., 174: 364-380.
10. Hutchison, C.S., 2014. Tectonic evolution of Southeast Asia. Geol. Soc. Malaysia Bull., 60: 1-18.
11. Richardson, J.A., 1946. The stratigraphy and structure of the arenaceous formation of the Main Range foothills, FMS. Geol. Mag., 83: 217-229.
12. Meng, C.C., B. Sautter, M. Pubellier, D. Menier, C.W. Sum and A. Kadir, 2014. A geological features of the Kinta valley. Platform, 10: 2-14.
13. Metcalfe, I., 1999. Devonian and carboniferous conodonts from the Kanthan limestone, Peninsular Malaysia and their stratigraphic and tectonic implications. Proceedings of the 14th International Congress on the Carboniferous and Permian, August, 17-21, 1999, Calgary, Canada, pp: 552-579.
14. Rastall, R.H., 1927. The limestone of the Kinta Valley, Federated Malay States. Geol. Mag., 64: 410-432.
15. Foo, K.Y., 1983. The Palaeozoic sedimentary rocks of Peninsular Malaysia-stratigraphy and correlation. Proceedings of the Workshop on Stratigraphic Correlation of Thailand and Malaysia, September 8-10, 1983, Haad Yai, Thailand, pp: 1-19.
16. Fatihah, R. and Y.E. Beng, 2000. The characteristics and origin of some limestone caves in the Sungai Perak Basin. Warta Geolog., Vol. 26,
17. Searle, M.P., M.J. Whitehouse, L.J. Robb, A.A. Ghani and C.S. Hutchison *et al*., 2012. Tectonic evolution of the Sibumasu-Indochina terrane collision zone in Thailand and Malaysia: Constraints from new U-Pb zircon chronology of SE Asian tin granitoids. J. Geol. Soc., 169: 489-500.
18. Meng, C.C., M. Pubellier, A. Abdeldayem and C.W. Sum, 2016. Deformation styles and structural history of the Paleozoic limestone, Kinta Valley, Perak, Malaysia. Bull. Geol. Soc. Malaysia, 62: 37-45.
19. Rajah, S.S., 1979. The Kinta Tinfield, Malaysia. Geo. Soc. Malaysia Bull., 11: 111-136.
20. Ingham, F.T. and E.F. Bradford, 1960. The Geology and Mineral Resources of the Kinta Valley, Perak. Federation of Malaya, Kuala Lumpur, Malaysia, Pages: 347.
21. Pierson, B.J., S. Kassa, H. Tsegab, A.A. Kadir, W.S. Chow, A.W. Hunter and Z.T.H. Zuhar, 2011. Sedimentology of the Palaeozoic limestone of the Kinta valley, Malaysia. Proceedings of the 1st EAGE South-East Asia Regional Geology Workshop on Palaeozoic Limestones of South-East Asia and South China, December 2011, European Association of Geoscientists & Engineers, The Netherlands, pp: cp-272-cp-272.
22. Gregg, J.M. and D.F. Sibley, 1984. Epigenetic dolomitization and the origin of xenotopic dolomite texture. J. Sediment. Res., 54: 908-931.